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Association between water and sanitation service levels and soil-transmitted helminth infection risk factors: a cross-sectional study in rural Rwanda

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Abstract: Soil-transmitted helminth (STH) infections are one of the most prevalent neglected tropical diseases in the world. Drug treatment is the preferred method for infection control yet re-infection occurs rapidly, so water and sanitation represent important complementary barriers to transmission. This cross-sectional study set out to observe STH risk factors in rural Rwandan households in relation to the Sustainable Development Goal water and sanitation service levels. Survey and observation data was collected from 270 households and 67 water sources in rural Rwanda and was processed in relation to broader risk factors identified from the literature for the role of water and sanitation in STH infection pathways. The study found a significant association between higher water and sanitation service levels and lower STH infection risk profiles for both water and sanitation. However, variability existed within service level classifications, indicating that greater granularity within service level assessments is required to more precisely assess the efficacy of water and sanitation interventions in reducing STH infection risks.

Keywords: Rwanda, soil-transmitted helminth, water, sanitation, neglected tropical diseases

1 INTRODUCTION

Soil-transmitted helminths (STH) are intestinal worms whose ova are passed in the faeces of an infected person or animal and only mature to an infective stage after contact with soil for several days or weeks. *Ascaris lumbricoides*, *Trichuris trichiura* and hookworm are STH species prioritised on the list of neglected tropical diseases (NTD) for global morbidity elimination (WHO, 2018). A highly prevalent infection, around 1.5 billion people are estimated to live with STHs (WHO, 2018) with 21-34% of the worldwide burden estimated to be within Sub-Saharan Africa (Hotez and Kamath, 2009). Agencies plan to ensure 75% of children aged 2-14 in endemic areas are treated with mass drug administrations (MDA) in schools by 2020 (Anderson et al., 2017; Ásbjörnsdóttir et al., 2017).

However, there is scepticism that treatment of children alone will successfully interrupt the transmission pathways in isolation of complementary interventions (Brooker et al., 2015a), as the high infection burden of adults as well as zoonotic and environmental sources serve to reinfect children (Ásbjörnsdóttir et al., 2017). This is evidenced by STH reinfection having been shown to occur in one in three children within three months of treatment (Jia et al., 2012). Rolling out population-wide MDAs would be a major step yet with limited government and donor resources these strategies are not currently employed and, even in such cases, environmental risks (understood as the wider environment within which families live, not just the natural environment) would remain a major barrier to disease management and eradication. As such, actions which reduce the environmental risks associated with STH infection are now widely recognised as vital complementary tools in the struggle to protect vulnerable communities from this particular disease burden (Grimes and Templeton, 2016).

Better exploitation of water, sanitation and hygiene (WASH) interventions to prevent STH reinfection and reduce the reliance on MDAs is frequently suggested as an appropriate environmental risk reduction strategy (Campbell et al., 2016; Strunz et al., 2014). Although "WASH is a key causal pathway to reduce environmental contamination and eventually break transmission" (Campbell et al., 2018, p56), the challenge lies in the complex causal pathway which is shaped by contextual factors around settings (e.g. built and natural environment, behavioural patterns) and subtle differences in the transmission mechanisms of STH species (Grimes and Templeton, 2016). Consequently, there is currently limited evidence about the relationship between STH environmental risks and WASH scheme design which might help practitioners adapt and better target their programmes (Campbell et al., 2018; Grimes and Templeton, 2016).

To track progress towards the Sustainable Development Goals (SDGs), the WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP) has defined a set of service levels (see Table 1). This monitoring programme provides assessments of service quality, from a 'safely managed' classification to 'unsafe' classifications (WHO/UNICEF, 2017). The categories are used to track progress at country, regional and global levels towards the SDGs, with monitoring statistics presented in terms of the percentage of population within a geographical area reaching each stage of the service level ladder (data is available from: WHO/UNICEF, 2019). Those estimates are largely drawn from representative household surveys in which harmonised questions are used to collect data to classify households at different levels on the service level ladder, with those household classifications then aggregated and extrapolated into the population-level estimates. However, beyond the SDG monitoring, the service level questions and framework are now used widely by governments, NGOs and other agencies in planning and monitoring their WASH projects and programmes. So, although designed as a global progress monitoring system and therefore perhaps not intentionally prescriptive at a practitioner-level, these targets represent hugely influential markers of programme success at project level. In that context, there remains questions regarding how appropriate these targets are for assessing STH infection risk protection (Campbell et al. 2018) and, relatedly, there has been no empirical assessment of whether the SDG service levels for water and sanitation are good predictors or even sufficient indicators of STH risk.

Beyond this general context, national need in Rwanda is especially high. The country has been identified as a 'less feasible' country for interrupting the transmission of STH (Brooker et al., 2015b) and Rwanda's households have been scored 0.2/10 for their capability to prevent STH transmission (Brooker et al., 2015b). This implies a pressing need to understand workable STH control solutions in this context. In response to these challenges, this paper uses a case study from Rwanda to (i) assess whether progress towards achieving the SDGs reduces the scale of STH-associated risk factors; (ii) provide evidence on the scale of household risks that can be inferred from STH transmission pathways; and (iii) discuss the role of WASH interventions in preventing STH transmission.

Table 1 - WHO-UNICEF Joint Monitoring Programme Service Ladders for Water Supply and Sanitation (WHO/UNICEF, 2017)

Service Level	Water Supply	Sanitation
Safely Managed	Drinking water from an improved water source[1] which is located on premises, available when needed and free from faecal and priority chemical contamination	Use of improved facilities[2] which are not shared with other households and where excreta are safely disposed in situ or transported and treated off-site
Basic	Drinking water from an improved source, provided collection time is not more than 30 minutes for a roundtrip including queuing	Use of improved facilities which are not shared with other households
Limited	Drinking water from an improved source for which collection time exceeds 30 minutes for a roundtrip including queuing	Use of improved facilities shared between two or more households
Unimproved	Drinking water from an unprotected dug well or unprotected spring	Use of pit latrines without a slab or platform, hanging latrines or bucket latrines
Surface Water / Open Defecation	Drinking water directly from a river, dam, lake, pond, stream, canal or irrigation canal	Disposal of human faeces in fields, forests, bushes, open bodies of water, beaches and other open spaces or with solid waste

Note: 1) "Improved drinking water sources are those that have the potential to deliver safe water by nature of their design and construction, and include: piped water, boreholes or tubewells, protected dug wells, protected springs, rainwater, and packaged or delivered water"; 2) "Improved sanitation facilities are those designed to hygienically separate excreta from human contact, and include: flush/pour flush to piped sewer system, septic tanks or pit latrines; ventilated improved pit latrines, composting toilets or pit latrines with slabs".

2 MATERIAL AND METHODS

The study was undertaken in the rural Matyazo sector of the Ngororero district in the western area of Rwanda. Matyazo has an approximate population of 26,000 (Republic of Rwanda, 2013a) with 3603 households lying within the study area. Three administrative cells (Rutare, Gitega and Binana) were selected as containing households which aligned with Categories 1-3 of Rwanda's *ubudehe* system of poverty status (Ministry of Local Government, 2016). In June and July 2018, household surveys were conducted in 270 households *[CI = 5.74%; CL = 95%]* and observation data collected for 67 water sources that served those households. Data collection included all villages in Matyazo sector, with households selected via a geographically-driven sampling frame in which villages were mapped and zoned, and households purposively selected from each zone to cover the geographical extent of villages. Adult household members were interviewed face-to-face in English with a Kinyarwanda language translator present. At the start of the visit, the study was introduced by the researcher and translator and informed consent to participate was obtained. Ethical approval to conduct this study was granted by the Cranfield University Research Ethics Committee (REF: CURES Project Approval: 5666).

Survey questions covered gender, number of household inhabitants, matriarchal and patriarchal education, number and type of household livestock, primary drinking water source, water collection time, daily number of jerry cans of water used, water treatment methods, handwashing drainage location, latrine age, latrine flood frequency and number of people from a different household that shared the latrine. Daily water usage was estimated in litres from the size of jerry cans observed. Additional questions adapted from the JMP methodology were used to ensure that the baseline coverage of JMP service levels classifications was valid and processed according to the standard methodology (WHO/UNICEF, 2017). The household drinking water source and sanitation facilities were identified and assessed for STH risks, as explained below. Although hygiene facilities are considered important as part of an STH control strategy they were not included in this study due to the difficulty in assessing hygiene orientated behaviours such as hand washing via survey and cross-sectional observational methods.

Data on water and sanitation facilities were classified based on an assessment of risks identified in the literature (as displayed in Table 2 and summarised here). Firstly, focusing on sanitation, it has been shown that latrines with a vent pipe reduce STH infection risk over other types of latrines (Freeman et al., 2015) and cement floors reduce transmission risk of some STH species but not all (Baker and Ensink, 2012). Similarly, households with more than six permanent residents are correlated with increased likelihood and intensity of STH infection (Traub et al., 2004). Freeman et al. (2015) correlated a lower STH risk with continuous availability of cleansing material (water or tissue), poor latrine structural integrity and superficial latrine cleanliness so these were considered risks during observations. Similarly, latrine flooding has been proposed as a potential cause of the spatial variability of STH prevalence (Steinbaum et al., 2017). Mud walls have been identified as a potential transmission zone so were included as a risk (McMahon et al., 2011). Whilst known to be a causative pathway of diarrhoeal illness (Briceño, Coville and

Martinez, 2015), flies are also able to carry helminth ova (Maipanich et al., 2008), so may constitute an additional STH transmission pathway. Finally, households with latrines outside of the premises appear to have a higher prevalence of STH infection (Worrell et al., 2016), due to usage by passers-by which causes hotspots of transmission.

Table 2 – Soil Transmitted Helminth Infection Risks Identified in Literature

Risk Category	Risk Type
Sanitation	• >6 people per household (Traub et al. 2004) • No vent pipe (Freeman et al. 2015) • Non-cement floor (Baker & Ensink, 2012) • No cleaning material (Freeman et al. 2015) • Poor latrine structural integrity (Freeman et al. 2015) • Visibly unclean latrine (Freeman et al. 2015) • >6 people per household (Traub et al. 2004) • Latrine has mud walls (McMahon et al., 2011) • Latrine has inadequate drainage (Steinbaum et al., 2017) • Flies are present (Maipanich et al., 2008) • Latrine is used by passers by (Worrell et al., 2016)
Water Supply	• Farmland within 30m of source (Freeman et al. 2015; Strunz et al. 2014) • Lack of concrete apron (Sphere Project, 2011) • Inadequate water source drainage (Steinbaum et al., 2017) • Storage with a wide opening (Wolf et al., 2018) • Ineffective treatment (Strunz et al., 2014) • Visible turbidity (Uwimpuhwe et al., 2014)

Secondly for water supply, lack of a cement apron around the water source and inadequate drainage has been shown to exacerbate STH infection risk (Steinbaum et al., 2017). The application of excreta to farmland as fertiliser may contaminate water sources via the same process as latrines if there is less than the recommended 30m horizontal separation (Sphere Project, 2011). Drinking water storage in a container with a wide opening is associated with diarrhoea due to scooping water with dirty receptacles (Wolf et al., 2018), which also has the potential to transmit STH ova. Household drinking water treatment has been shown to reduce STH risk (Strunz et al., 2014); whilst chlorine is not effective against helminth ova (Jimenez-Cisneros and Maya-Rendon, 2007), boiling (Maya et al., 2012) and ultrafiltration (Vestergaard, 2014) are. These methods could reduce STH transmission risk if always performed. Pathogens can adsorb to particles of turbidity in water (Uwimpuhwe et al., 2014), so may facilitate increased transmission of STH via similar mechanisms.

The above risks were identified via a literature review and whilst they may not constitute every possible STH infection risk they represent an extended set of known and inferred risks that could be assessed via the survey and observation methods within this study. Data from surveys and observations were entered into Microsoft Excel for cleaning, structuring and formatting for analysis. Statistical analysis was performed using SPSS® (version 22.0, IBM, Chicago, Illinois, USA). Frequency distribution tests characterised respondent demographics, water source types and sanitation levels across JMP classification. Pearson's chi squared test (significance level $p \leq 0.05$) assessed the correlation between risks and JMP classification of water sources and sanitation facilities so as to assess the accuracy with which JMP classifications are a predictor of high and low risk households.

3 RESULTS

The survey was conducted across households in three of Matyazo's administrative cells of Rutare (n=55), Gitega (n=94) and Binana (n=121). Study results are presented below for water supply and sanitation. Basic coverage of water supply reached 60% of households (n=155), whilst 26% (n=67) had limited access, and unimproved or poorer quality water sources were used by 14% (n=36). All improved sources were protected springs, with water being collected either directly at the source or piped to a tap-stand. Unimproved sources were typically shallow pools from springs, and surface water sources were streams. The average amount of water used per person per day was 13.4 litres and the average collection time was 31.7 minutes. Some form of drinking water treatment was used by 174 households (64%; n=270), with 65 households always treating their drinking water. Of the treatment methods used, 143 households reported boiling (82%), 23 used a 'LifeStraw® Family 2.0' water filter (13%), seven used Sûr'Eau - sodium hypochlorite (4%), two let the water settle (1 %) and two used black salt (1%).

Table 3 shows the frequency of observed risks as a function of drinking water JMP classification. Although having an improved water source is associated with reductions in several types of risk, ineffective treatment, inadequate water source drainage and farmland within 30 m of the source remained prevalent as the household drinking water service classification improved. A Pearson's chi squared test to assess the association between the number of facilities with a specified risk against JMP water service level categories shows a reverse correlation between an increase in risks and lower JMP source classification *($X^2 = 215.39$, $P<0.001$)*. In Figure 1, it is clear that whilst at each service level there are still a number of risks experienced by a varying proportion of households, the number decreases with improved service levels. However, the variability which is evident at each service level implies that there are more or less risky forms of each type of service. For example around a quarter of households with basic service levels exhibit three or more risk factors – the same as for around 60% of households with an unimproved water source.

Table 3. Distribution of identified risks by drinking water JMP classification

JMP classification	**Unimproved**	**Limited**	**Basic**
Count	36	67	155
No cement apron at source	31%	0%	3%
Farmland within 30m of source	44%	70%	40%
Inadequate water source drainage	56%	54%	60%
Storage with a wide opening	3%	3%	1%
Ineffective treatment	56%	81%	83%
Visible turbidity	8%	6%	3%

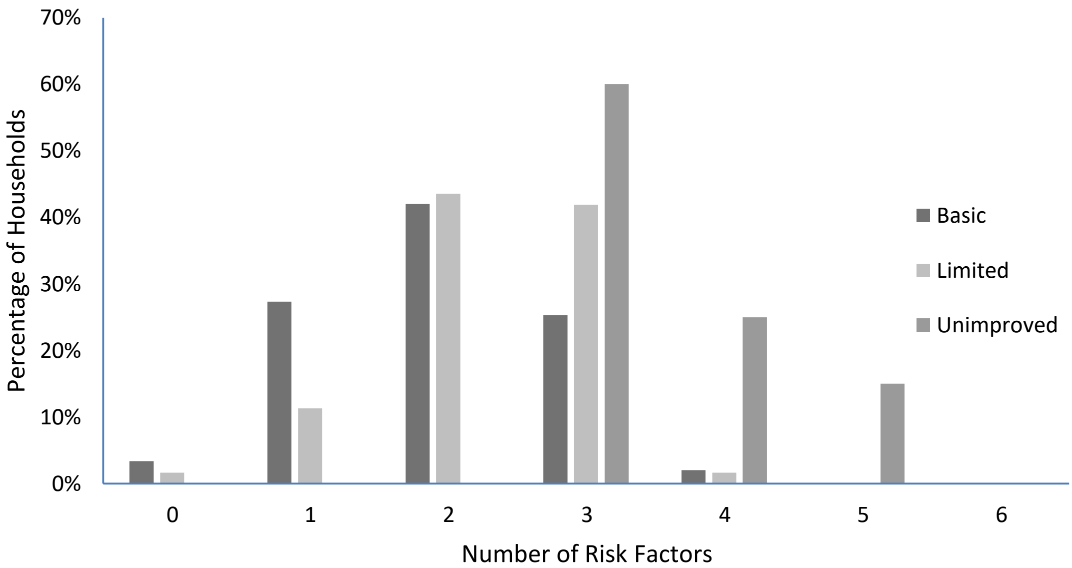

Figure 1. Proportion of households (%) to total number of drinking water risks, categorised by JMP classification of water source

The quality of sanitation in the region was generally very low; latrine coverage was high, albeit mostly unimproved in nature (91.4%, n=257). No latrines were classified as limited as there were no basic latrines surveyed that were used by more than one household. The average number of people per latrine was 5.5 (n=257) and the average age of latrine structures was 3.2 years (n=257). Latrine superstructures had either collapsed or were under construction due to heavy rains in 14 households. Table 4 shows the frequency of risks by sanitation JMP classification level. As shown, for eight out of eleven risk factors unimproved latrines were more likely to have risk factors associated with them than for basic latrines. However, in three risk categories basic latrines were either very similar or higher than for unimproved latrines. For example there were only very marginal differences in terms of the availability of cleaning materials and use by passers-by, and a small difference also reported with regards to poor drainage.

Table 4. Distribution of identified risks by sanitation JMP classification

JMP Classification	Basic	Unimproved
Count	22	235
>6 people per household	18%	29%
No vent pipe	55%	90%
Non-cement floor	0%	90%
No cleaning material	82%	81%
Poor structure	14%	25%
Visibly unclean	23%	90%
Latrine floods	23%	29%
Latrine has mud walls	59%	89%
Latrine has inadequate drainage	45%	26%
Flies are present	23%	41%
Latrine is used by passers-by	9%	8%

Figure 2 illustrates the distribution of risks for unimproved and basic latrines, suggesting that basic latrines are associated with a lower number of risk factors. Pearson's chi squared test again assessed the association between the distribution of risks and JMP sanitation service level category. Again, this supports a reverse correlation between an increase in number of risks and lower sanitation service levels *($X^2 = 171.12$, $P<0.001$)*. Several STH risks were intrinsic to the JMP classification of sanitation as basic or unimproved (e.g. not having a vent pipe) so this associated is not unexpected; however the figure also illustrates the breadth in the number of risk factors at each level. It appears possible to have unimproved latrines that have a lower number of risk factors than basic latrines, and within a specific category there is considerable distribution in the number of risks identified.

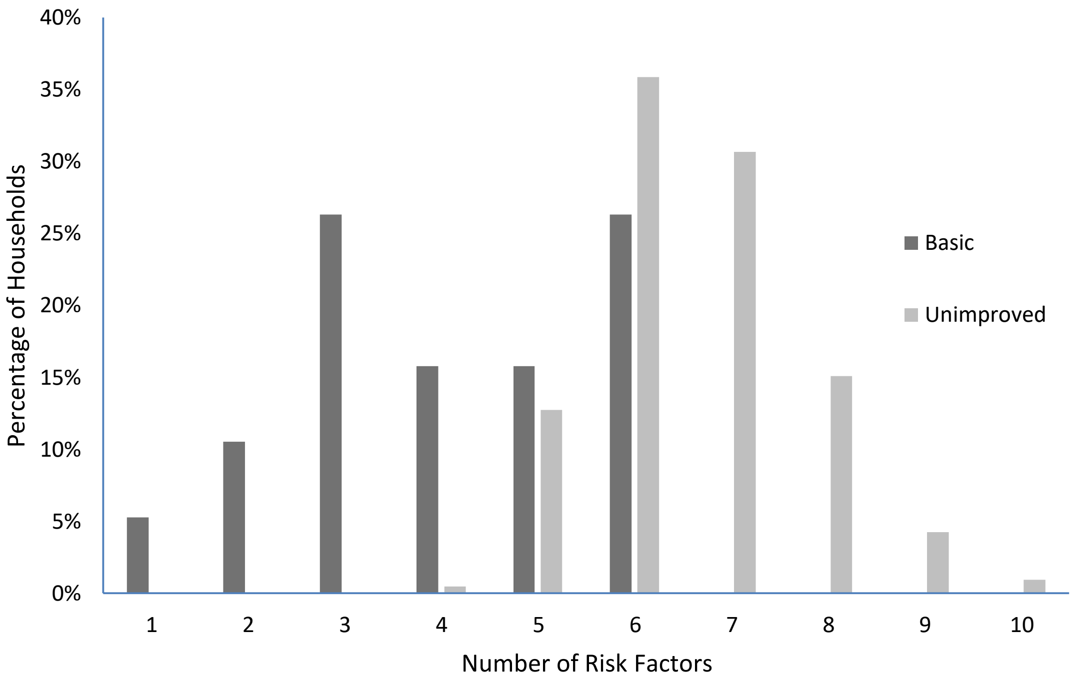

Figure 2. Proportion of households (%) exposed to total number of sanitation risks, as broken down by JMP classification of sanitation

4 DISCUSSION

Results from this study support an association between lower JMP service level classifications and increased STH risk. As the service level classifications are largely driven by the health requirements of hygienically separating human populations from their faeces and ensuring faecal pathogens do not contaminate water supply, it is predictable that higher service levels should lead to lower STH transmission (Campbell et al. 2018), as faeces represent a key transmission pathways for all major STH species. This further validates the usefulness of the service level classifications as good markers for assessing the health protection provided by different water and sanitation arrangements. However, in the context of the need to protect against reinfection following MDAs as part of global STH eradication efforts, it is the observed variety in STD risks at each service level classification that implies there are additional factors not covered by those service levels which also contribute to and determine risk. This indicates a need to develop a more precise understanding of the type of facilities that most effectively reduce reinfection and the level at which they must be maintained.

A prior assessment from the literature identified 17 risk factors for water and sanitation, and five were identified in more than 50% of the households receiving basic services. For water, these were linked to poor drainage and treatment; for sanitation, they were related to a lack of effective vent pipes or cleaning material and mud walls in latrines. These represent potential focal points for the development of further guidance and assessment methods with regards to assessing water and sanitation provision in STH endemic areas. Similarly, there were both safer and less-safe unimproved services. Some unimproved latrines had an offset pit with a side chute excavated through the soil at a shallow angle. With no mechanism for the faeces to reach the pit through gravity, many latrines of this design could be described as 'sheltered open defecation'. These were invariability the latrines with the highest risk profiles so encouraging a more 'formal' unimproved latrine design could help reduce risks. As such, although the goal of government and development programmes should be to provide basic and, ideally, safely managed sanitation there is likely value in contexts such as rural Rwanda in providing short term guidance on improving the safety of unimproved latrines to reduce STH risks. Here, we note that in the Rwandan context, government policy for rural water supply favours gravity-fed schemes from protected springs (Republic of Rwanda, 2013b). This type of infrastructure was the major improved water source covered in the study and so the findings imply that in supporting the roll-out of such infrastructure there is a need for government and other actors to be conscious that there are important infrastructural and management attributes (as summarised in Table 2) that are likely to improve the efficacy of improved springs in terms of STH protection.

The tenor of this argument aligns with a recent opinion piece for the tailoring of WASH targets so to better account for STH and schistosomiasis risks (Campbell et al. 2018). That particular work applied a traffic-light system to the different service level classifications in the JMP which explicitly highlighted that the lowest service levels were unsafe for STHs and schistosomiasis, and that the highest service levels were safer. It also introduced some descriptive conditionalities to the service levels, noting that only clean facilities can be considered safe and that factors such as prevalence of shoe wearing among users of water supply facilities will impact infection risk. The analysis in this paper complements this work via the mapping of risk factors and empirical assessment of the prevalence of such factors within a high-risk, STH-endemic sub-Saharan African context. However, a limitation here is that analysis of the highest 'safely managed' service level was not included as none of the households assessed reached this level of service. This limits the ability to make an assessment across all levels of the SDG service level ladder. However, large areas of rural Africa where STHs are endemic are characterised by low service levels and therefore government and NGO policy is to increase services up to basic levels. In light of this, the need to better understand the variability in STH protection at a basic (and lower) service level(s) remains a relevant message.

This study benefitted from visiting households directly, which allowed the observation of a range of risks; however the emphasis on water and sanitation limited analysis of the true extent of possible STH risks. For example, livestock were observed in 85% of households where animal excreta was nearly universally uncontained and closer to the house than many latrines. The pathogen transmission risk when animals are in the household vicinity is large (Briceño, Coville and Martinez, 2015). Pigs are a source of human *Ascaris* infection and can also spread another helminth-based NTD, Cysticercosis (Hedley and Serafino Wani, 2015), whilst cattle can spread the *Taenia saginata* helminth following ingestion of infected human faeces (Strauss, 1985). There are also assessment bias challenges when conducting an observational risk assessment. In this study this was mitigated as all assessments were made by the lead author, but it would require further work to produce a replicable risk assessment approach that could be employed across different contexts. In addition, the approach employed in this study relies on the notion of risks as identified in the literature rather than direct measures of STH prevalence and incidence in the population using biomedical methods. Here, the study is also exposed to confounding bias between the infrastructural factors we used in the assessment process and how these relate to broader socio-economic factors that may drive risk. For example, households with higher standard infrastructure such as latrines with concrete aprons are likely to have higher levels of socio-economic development which may also protect them from STH risk. Finally, the analysis emphasises number of risks but does not make judgement of the relative magnitude of different risks. Despite these limitations, it is hoped that this paper provides direction, evidence and motivation to inform further work using such approaches at scale and across different settings to robustly define guidance on STH sensitive WASH programming.

5 CONCLUSIONS

The global eradication of STHs will require cross-sector work to reduce infection via MDAs with parallel efforts to prevent re-infection from human, animal and environmental sources. WASH provides an important part of that jigsaw by helping to provide a barrier to re-infection, especially from human sources. This paper presented a study that assessed whether the most widely used measures for assessing the quality of water and sanitation services are good predictors of STH risk. The results suggest that higher service levels do correlate with lower STH risks, indicating that they do partly predict such risks. Yet, it remains possible to have 'less risky' and 'more risky' water and sanitation at the same service level classification, meaning that simply owning and using facilities at those service level classifications provides only a partial picture of STH risk. In areas with endemic STH infection, water and sanitation communities and practitioners must consider broader risk factors to ensure facilities effectively protect against STH transmission without simply relying on service level classifications. These broader assessment criteria should include more robust assessments of drainage, location of facilities, maintenance and cleanliness, and usage patterns.

Authors' contributions: Mather designed and implemented the study and conducted initial analysis and interpretation of data. Jeffrey advised on the design, implementation, analysis and interpretation of data and manuscript preparation. Budge was involved in analysis and manuscript preparation. Hutchings was involved in analysis and led the interpretation of data and manuscript preparation.

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